International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Available at http://inpressco.com/category/ijcet

Research Article

State of the art of Damage Assessment of Rural Houses for Cyclonic Wind

Pradeep K. Goyal[†*]

[†]Dept. of Civil Engineering, Govt. Engineering College, Ajmer, Rajasthan, India

Accepted 05 Dec 2015, Available online 11 Dec 2015, **Vol.5, No.6 (Dec 2015)**

Abstract

This paper presents a state of the art review of damage assessment of rural houses for cyclonic wind. The tropical cyclones are one of the most serious threats to lives and property in the coastal region of India. The effort to reduce cyclone damage in coastal areas is of particular importance vulnerable to cyclones. Most of the buildings in the coastal region of India are of non-engineered and semi-engineered.Probabilistic description of cyclonic wind speed, damage observed in houses due to cyclonic wind are discussed. Different techniques to evaluate the damage of houses are also presented.

Keywords: *Cyclone, Damage, Vulnerability, Wind Speed; Rural Houses*

Introduction

Tropical cyclones are the most serious natural hazard in the coastal region of India. They cause loss of life and considerable damage to property when they hit the coastal region. Indian coastal region are subjected to severe cyclonic storms. Due to population growth along the coastal regions, buildings and other structures are being built up rapidly. The risk of damage of buildings/houses, human injury and death are increasing in the coastal regions. It is not possible to prevent the natural hazards, but the damages and other losses can be minimized by the proper disaster planning and management. Most of the houses are of non-engineered type with thatch roof and mud walls or semi-engineered with tiled or asbestos cement (AC) sheet roof and masonry walls in the coastal region of India. Developing countries are more vulnerable to cyclones than the developed countries. The east coast of India is more vulnerable to cyclone as compared to the west coast. It has been observed that the entire east coast is vulnerable to cyclones. The states of Tamil Nadu, Andhra Pradesh, Orissa and West Bengal are prone to cyclones. Every year a large number of houses are destroyed by cyclones associated with extreme wind speeds, particularly in the coastal regions of India. It has been observed that about four to five cyclones occur in the Indian coastal region, out of which one or two may be severe leading to heavy damage and destruction. Hence the problem of cyclone disaster mitigation is of national importance.

*Corresponding author **Pradeep K. Goyal**is woking as Associate Professor

Concept of Tropical Cyclones

Tropical cyclones are very powerful storms characterized by high winds rotating about a calm center of low atmospheric pressure. Tropical cyclones forms over the warm sea water when the ocean surface temperature exceeds 26^0 C or 27^0C. They occur within 5 to 30 degree latitude on either side of equator. Tropical cyclones become severe when they are located between 20^0 and 30^0 latitude. Tropical cyclones are named as Hurricanes in the Atlantic Ocean, Typhoons in the Pacific Ocean and Tropical cyclones in the Indian Ocean.

Tropical cyclones are large revolving vortices in the atmosphere extending horizontally from 150 to 1000 km with violent winds. Central region of the tropical cyclones termed as eye. The eye generally normally has an average radius of about 20 to 30 km. The pressure is the lowest and temperature is the highest in this region. The eye is surrounded by a ring of very strong winds (known as eye wall) extending on an average up to 30 to 50 km beyond the center (Bhandari *et. al.* 2011).

Fig.1: Different part of a cyclone

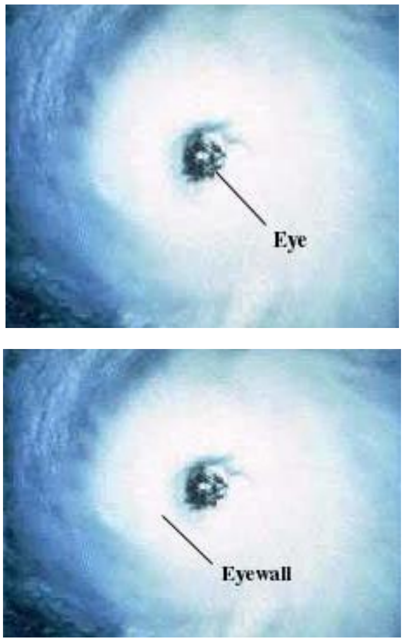

Fig.2: Eye and Eyewall of Tropical cyclones

This area is termed as zone of maximum wind. Fig.1 shows the different parts of cyclones. Eye and Eyewall of tropical cyclones are shown in Fig.2.

Quantification of Cyclones

The classification of tropical disturbances is followed by the India Meteorological Department in the way of Bengal and in the Arabian Sea as adopted by the World Metrological Organization (WMO) as shown in Table 1.

Table1: Classification of tropical disturbances

S.N.	Categories	Wind speed		
		Knots	Km/hr	m/s
1	Low pressure area	<17	<31	<8.75
2	Depression	17-27	31-49	8.75-13.9
3	Deep Depression	28-33	50-61	14.4-17.0
4	Cyclonic Storm	34-47	62-88	17.5-24.2
5	Severe Cyclonic Storm	48-63	89-118	24.7-32.4
6	Very Severe Cyclonic Storm	64-119	119-121	33-61.2
7	Super Cyclonic Storm	120 and more	222 and more	61.7 and more

Probabilistic description of cyclonic wind speed

Probability distribution of extreme cyclonic wind speed is a key parameter in determining the damage assessment of the buildings to cyclones. As a result, considerable studies have been made to identify the distribution of the cyclonic wind speeds for different regions from the recorded data. The homogeneous Poisson processare used widely to model the annual recurrence rate of cyclones (Batts *et al.*, 1980; Georgiou, 1983). A Poisson process model was developed to model the occurrence of cyclones in the coastal region using the cyclonic wind speed data (BalajiRao, 1993). Swami et. al. (1985) carried out extreme value analysis of peak winds as well as mean winds using EV Type-I distribution. Sharma (1985) used Gumbel (Type I) distribution for carrying out extreme value analysis in India. Gumbel (Type I), Frechet (Type II) and Log- normal probability distribution function for cyclonic wind speed in India have been proposed by Shanmugasundaram*et al*. (1989). Frechet distribution is found to the best fit to represent the cyclone wind speed in Indian coast except that of Orissa. In the case of Orissa, the lognormal distribution was found to be the best. Weibull distribution is the most appropriate model for Miami extreme-wind speeds (Georgiou, 1983). Further, Peterka and Shahid (1998) shown that the Weibull distribution provides a reasonable fit to the hurricane wind speed data at sites along the southeast coast of the US. Vickery *et al*. (2000) have carried out simulations of hurricanes by using an empirical track model. It has been confirmed that a Weibull distribution is appropriate for hurricane wind speed prediction. Stewart, G. (2003) used EV-Type I (Gumbel) probability distributions for annual maximum gust speeds for various locations in Northern Australia.

Classification of Buildings

All buildings have been classified into three main categories in India as (i) Non Engineered (NE) (ii) Semi-Engineered (SE) (iii) Engineered (E). Buildings constructed using the conventional building materials using local construction practices are termed as non-engineered building. Semi Engineered buildings, which are made intuitively from structural materials without proper design. Supervision may be through trained staff. Engineered Buildings are buildings, which have designed and constructed as per Indian standards (IS 15498:2004).Based on the construction materials used in walls& roofs, and the type of roof; pitched (P) or flat (F) the house types have been classified as shown in Table 2 (Lakshmana*et al*, 2002 & Vulnerability atlas of India).

Table 2: Classification of buildings

A1.Mud Wall(All Roofs)	Non-Engineered
A2.Unburned Brick Wall(All Roofs)	Non-Engineered
A3.Stone Wall (a) Sloping Roof (P) (b) Flat Roof (F)	Semi-Engineered
B1.Burned Brick Wall (a) Sloping Roof (P) (b) Flat Roof (F)	Semi-Engineered Engineered
C1.Concrete Wall (a) Sloping Roof (P) (b) Flat Roof (F)	Engineered
C2.Wood Wall(All Roofs)	Non-Engineered
C3.Ekra Wall(All Roofs)	Non-Engineered
X1.GI and other metal sheets(All Roofs)	Semi-Engineered
X2.Bamboo,Thatch Grass, Leaves etc.(All Roofs)	Non-Engineered

Damage observed for rural buildings from cyclonic wind

Most of the common houses in the coastal region of India are of non-engineered and semi-engineered. Somayaji and Kalyanaramam (1990) reported that wind damage in a cyclone affected areas may extend to hundreds of kilometres from the coast. The survey showed that higher percentage of failure occurred in Mangalore tiled roofing compared to country-tiled roofing in the 1989 cyclone. Failure was more common along eaves, roofs intersections and ridges. Apart from damage to roof, cyclones cause damage to walls as well. Severe wall damages were observed in houses with thick mud walls in the Andhra Cyclone of 1990. Somayaji *et al*. (1995) reported on the basis of inspection of damaged houses during past cyclonic storms and literature information, that failure of building components due to cyclonic wind was generally localised. The major damage to rural houses from cyclonic winds is limited to that of roofs. Damage to roofs includes flying of roof tiles, breakage of roofing sheets, failure of connections, failure of thatched roofs, failure of connections of roof element etc. It was also reported that cyclonic storms cause failure of houses, and compound walls.

Raju and Sinha (1998) reported that damage to residential houses due to Gujarat cyclone of June 1998 was found high in rural areas because of non-engineered constructions. Generally, walls constructed with Balastones in cement or mud mortar bricks collapsed. After the roof structure is damaged and the connectivity with supporting walls is weakened, the walls too become vulnerable to failure. Damage to other residential houses was moderate and restricted mostly to the sloped roofs. Damage was high in the roof structures and the roof coverings. Roofs without trusses or rafters reported maximum damages. Failure was more common along the eaves, ridges and other discontinuities. Damage was observed maximum in old and poorly constructed houses. Engineered houses and RCC constructions suffered little or no damage.

A cyclone damage survey was conducted by Structural Engineering Research Centre (Shanmugasundaram *et al*., 2000) after the severe cyclone which hit the east coast of India, near Kakinada, Andhra Pradesh, South India, during Nov', 1996. In this region, most of the common residential houses were of non-engineered type with thatch roofs and mud walls or semi-engineered with tiled or asbestos cement (AC) sheet roofs and masonry walls. Following failures observed include complete collapse of roofing system in most of houses and semi-engineered houses with thatch, tiles and AC sheets, failure of connections, failure of walls. It was reported that due to this cyclone more than half-a-million thatched houses were damaged or collapsed. These types of damage have also been found during Gujarat cyclone, 98(Raju&Sinha1998) and Orissa super cyclone, 99(Arya 2000).

Different technique used to describe the vulnerability of building

Vulnerability assessment of each type of houses and cluster of different types of houses in a locality is important in relation to wind damage assessment. The damage assessment methods are classified as qualitative and quantitative methods. Qualitative damage is determined using damage scale according to Indian standard procedure (IS 15499:2004). Damage to Roof of non-engineered and Semi-engineered construction is determined as per Table 3. Damage to walls made of mud, reinforced mud and brick/stone /cement concrete block masonry is determined as per Table 4.

Table3: Damage to Roof of Non-engineered and Semi-engineered construction

Damage	Description
Marginal	Failure of connections.
Medium	Roof/Wall cladding in bad condition or partial failure of roof (<50 percent)
Heavy	Failure of roof/Wall cladding, failure of connections
Total	Failure of walls, failure of complete roof, almost totally damaged.

Table 4: Damage to Walls Made of Mud, Reinforced Mud

Damage	Description
Marginal	Minor cracks in walls, plaster peeled off, penetration of moisture in inside wall
Medium	Heavy cracks in walls, no tilting of structures, plaster peeled off, wall material weathered at reaction locations
Heavy	Tilting of walls, portion of wall damaged or partial collapse.
Total	Failure of the wall

From the wind damage point of view, India has been divided into six zones as per basic wind speeds as shown in Table 6 (Bhandari *et. al.* 2011).

Table 6: Division of damage risk zone

Speed of cyclone m/s	Zone
55	Very high damage risk zone -A
50	Very high damage risk zone -B
47	High damage risk zone
44	Moderate damage risk zone-A
39	Moderate damage risk zone-B
33	Low risk zone

The damage risk scale are used for developing the house vulnerability tables for damage risk to buildings from wind storms as shown in Table 7(Bhandari et. al. 2011).

Table7: Damage Risk Scale

S.N.	Damage Risk Scale	Description
1	Very High Damage Risk(VH)	Damage is more as compared to high damage risk (H).
2	High Damage Risk(H)	Boundary wall overturn; failure of walls; failure of complete roof; heavy damage to non-engineered/ semi-engineered constructions/houses.
3	Moderate Damage Risk(M)	Loose tiles of clay fly, roofs sheets fixed to batten fly; moderate damage to non-engineered /semi-engineered buildings.
4	Low Damage Risk(L)	Loose metal or fibre cement sheets fly, very little damage to non-engineered /semi-engineered houses.
5	Very Low Damage Risk(VL)	Generally similar to Low Risk but expected to be very limited in extent.

There are two quantitative methods to assess vulnerability for structures, namely (i) component-based approach and (ii) direct approach. Using component-based approach, the vulnerability of the structure is calculated based on the component vulnerabilities and their interactions. For this, the vulnerability of the each components of a structure is determined separately. Vulnerability of house is determined for the entire structure using direct approach. Holmes (1996), Stubbs and Perry (1996), Unanwa et. al. (2000),Pinelli *et al* (2004), Vickery et. al. (2006) are the examples of wind vulnerability models developed using the component-based approach. Examples of vulnerability models using the direct approach can be found Sparks *et al*. (1994),Huang *et al*. (2001)**,**Khanduri and Morrow (2003).

Sparks *et al*. (1994) used insurance claim records of Hurricane Hugo and Hurricane Andrew to determine relationships between damage ratio and gradient wind speed, for different building components. From the cumulative distribution of strength of any element, vulnerability curve for a fully engineered structure was derived by Holmes (1996). Vulnerability model was derived from the performance of different building components and their corresponding relative importance by Stubbs and Perry (1996).

Sill and Kozlowski (1997) presented a method for predicting the percentage of damage within an area as a function of wind speed and various other parameters, by beginning with several logical hypotheses and developing these into expression for damage. Murlidharan*et al*. (1997) proposed theknowledge-based system for damage assessment and vulnerability analysis of structures subjected to cyclones.Unanwa*et al*. (2000)proposed an approach for hurricane wind damage prediction using the concept of wind damage bands.Huang *et al*. (2001) developed a structural vulnerability model using claim and loss information from Hurricanes Hugo and Andrew obtained from a very large insurer. Filliben*et al*. (2002) presented a conceptual framework for the estimation of damage matrices under extreme wind loads. Lakshmanan and Shanmugasundaram (2002) proposed a simple analytical model for predicting the damage scenario of houses considering the cyclone wind field, and capacity wind speed of various types of building. Rosowsky and Ellingwood (2002) presented an overview on performance-based designmethodology for assessing probable response of light-frame residential construction exposed to various levels of natural and man-made hazards. Cope *et al*. (2003)developed a probabilistic model which was based on a discretized set of structural failure modes and their relationship to peak wind speed, building classification, and location in Florida. Khanduri and Morrow (2003) also presented a similar method of assessment of vulnerability and a methodology to translate a known vulnerability curves from one region to another region, where detailed loss data are available. Ellingwood and Rosowsky (2004) proposed a methodology to carry out fragility analysis for light-frame wood structures subjected to wind and earthquake hazards. Pinelli *et al*. (2004) presented a probabilistic framework for the estimation of annual damages due to windstorms in the state of Florida. Lee and Rosowsky (2005) conducted a fragility assessment for roof sheathing failure in high wind regions for low rise wood frame structures. Li and Ellingwood (2006) proposed a probabilistic framework for evaluating the reliability of low-rise wood residential construction in hurricane-prone areas of the United States. Vickery*et al*. (2006) presented an overview of the damage and loss models used in the HAZUS-MH Hurricane Model.

Li and Ellingwood (2009) presented a comparative risk assessment framework for multihazards assessment for hurricane and earthquake hazards. Goyal *et al*. (2012) presented a method for evaluating vulnerability of rural houses to cyclonic wind for countries where damage data are inadequate.

Conclusion

Techniques for damage assessment of rural houses to cyclonic wind are discussed available in the literature. Damages observed for rural houses due to cyclonic are presented. It is seen damage assessment for rural houses is the major issue of cyclone disaster mitigation for coastal region of India. Qualitative damage assessment can be determined for different types of houses (NE, SE, E) using the damage scale.

References

Arya, A.S. (2000). Guidelines for Reconstruction of Buildings in Cyclone Affected Areas in Orissa. HUDCO, New Delhi.

Balaji Rao,k.,Thomas,k.c and AppaRao,T.V.S.R.(1993). Stochastic modeling of Cyclonic wind speeds.,Proc.Third Asia Pacific Symposium,Hong Kong,Vol.1,Dec.13-15,pp. 543-548.

Batts, M. E., Russell, L.R. and Simiu, E. (1980). Hurricane wind speeds in the United States. *Journal of the* Structural Division, ASCE, 106(ST10), 2001-2016.

Bhandari, N.M., Krishna, P. and Krishen, K. Wind storms, damage and guidelines for mitigative measures, Department of Civil Engineering, Indian Institute of Technology, Roorkee, p. 11, Document No. IITK-GSDMA-Wind03-V3.0 (2011).

Cope, A., Gurley, K., Pinelli, J.-P., and Hamid, S. (2003). A Simulation Model for Wind Damage Predictions in Florida.*Proceedings of the 11th International Conference on Wind Engineering*, Texas Tech Univ., Lubbock, TX

Ellingwood, B. R., Rosowsky, D. V., Li, Y. and Kim, J. H. (2004). Fragility Assessment of Light-Frame Wood Construction Subjected to Wind and Earthquake Hazards. *Journal of Structural Engineering*, ASCE, 130(12), pp. 1921-193

Filliben, J.J., Gurley, K., Pinelli, J.-P., Simiu, E. and Subramanian, C. (2002). Fragility Curves, Damage Matrices, and Wind Induced Loss Estimation. *Proceedings of the Third International Conference on Computer Simulation in Risk Analysis and Hazard Mitigation*, Sintra, Portugal, pp. 119-

Georgiou, P.N., Davenport, A.G. and Vickery, B.J. (1983). Design Wind Speeds in Regions Dominated by Tropical Cyclones. *Journal of Wind Engineering and Industrial Aerodynamics*, 13, 139-1

Goyal P.K., Datta T.K. & Vijay V.K. 2012. Vulnerability Assessment of Rural Houses to Cyclonic wind. International Journal of Disaster Resilience in the Built Environment, Vol.3 (1), p. 20-41, Emerald

Huang, Z., Rosowsky, D.V. and Sparks, P.R. (2001). Long-term Hurricane Risk Assessment and Expected Damage to Residential Structures.*Reliability Engineering and System Safety*, 74(3), pp. 239–2

Holmes, J. (1996). Vulnerability Curves for Buildings in Tropical Cyclone Regions.*Proceedings of 7th ASCE Specialty Conference on Probabilistic Mechanics and Structural Reliability*, Worcester, Mass, pp.78–

IS: 15498 (2004). Guidelines for Improving the Cyclonic Resistance of Low Rise Houses and other Buildings/Structures.*Bureau of Indian Standard*, ManakBhawan, New D

IS: 15499 (2004). Guidelines for Survey of Housing and Building Typology in Cyclone prone areas for Assessment of Regions and Post Damage Éstimation.*Bureau of Indian Standard*, ManakBhawan, New Delhi.

Khanduri, A. C. and Morrow, G. C. (2003).Vulnerability of Buildings to Windstorms and Insurance Loss Estimation*. Journal of Wind Engineering and Industrial Aerodynamics*, 91(4), pp. 455–467

Lakshmanan, N. and Shanmugasundaram, J. (2002).A Model for Cyclone Damage Evaluation.*Journal of. Institution of Engineers* (*India*), 83, pp. 173-179

Lee, K.H. and Rosowsky, D.V. (2005).Fragility Assessment for Roof Sheathing Failure in High Wind Regions.*Engineering Structures*, 27(6), pp. 857–868

Li, Y. and Ellingwood, B.R. (2006). Hurricane Damage to Residential Construction in the US: Importance of Uncertainty Modeling in Risk Assessment. *Engineering Structures*, 28(7), pp. 1009–1018

Li, Y. andEllingwood, B.R. (2009).Framework for Multihazard Risk Assessment and Mitigation for Wood-Frame Residential Construction.*Journal of Structural Engineering*, ASCE, 135(2), pp. 159-16

Murlidharan, T.L., Durgaprasad, J. and AppaRao, T.V.S.R (1997). Knowledge-Based Expert System for Damage Assessment and Vulnerability Analysis of Structures Subjected to Cyclones. *Journal of Wind Engineering and Industrial Aerodynamics*, 72(1-3), pp. 479–491

Peterka, J.A., Shahid ,S.(1998). Design gust wind speed in the United States. Journal of Structural Engineering, ASCE 124(2): 207–1

Pinelli, J-P., Simiu, E., Gurley, K., Subramanian, C., Zhang, L., Cope, A., *et al*. (2004).Hurricane Damage Prediction Model for Residential Structures.*Journal of Structural Engineering*, ASCE, 130(11), pp. 1685–

Raju,D.V.S.,andSinha,J.(1998). Vulnerability and Failure Study of Built Environment in Gujrat Cyclone.National Conference on Disaster & Technology, Manipal

Rosowsky, D.V. and Ellingwood, B.R. (2002). Performance-Based Engineering of Wood Frame Housing: Fragility Analysis Methodology. *Journal of Structural Engineering*, ASCE, 128(1), pp. 32–38.

Shanmugasundaram,J.,Annamalai,G.,and Venkateswarli,B.(1989). Probabilistic models for cyclonic wivd speeds in India.Proceedings of the second Asia-Pacific Symposium on wind engineering,Beijing,China.,pp. 123-1

Shanmugasundaram,J. *et al* (2000). Cyclone damage to building and structures--- a case study. J. Wind Eng. Ind. Aerodyn. 84, 369-380

Sharma,M.C.(1985). State-of-art-report on wind zoning in India.Proceedings of Indo-US Workshop on wind disaster mitigation.Vol.1,17-20 December,pp. 47-60.

Sill, B.L. and Kozlowski, R.T. (1997). Analysis of Storm Damage Factors for Low- rise Structures. Journal of Performance of Constructed Facilities, ASCE, 11(4), pp. 168–177.

Somayaji, S., Prasad, A.M., Mathews, M.S., Krishnamoorthi, C.S. (1995).Types of Building Failures due to Cyclonic Winds.*Proceeding of Ninth International Conference on Wind Engineering*, New Delhi, India, 4, pp. 1979-1988

Somayaji,S.,andKalyanaraman,V.(1990). Andhra cyclone of May 90:Damage to structures. Civil Engineering and Construction Review,3(11),37-40.

Swami,B.L.(1985). Study of extreme winds in India based on Gumbels' distribution.Proc.of National Seminar on Tall Reinforced Concrete chimneys,New Delhi

Sparks, P.R., Schiff, S.D. and Reinhold, T.A. (1994). Wind Damage to Envelopes of Houses and Consequent Insurance Losses. *Journal of Wind Engineering and Industrial Aerodynamics*, 53(1-2), pp. 145–155

Stewart,G.M.(2003). Cyclone damage and temporal changes to building vulnerability and economic risks for residential construction. *J. Wind. Eng. Ind.Aerodyn.*91,671-691.

Stubbs, N. and Perry, D.C. (1996).A Damage Simulation Model for Buildings and Contents in a Hurricane Environment.*Proceedings of ASCE Structures Congress XIV*, ASCE, Chicago, 2, pp. 989–9

Unanwa, C.O., McDonald, J.R., Mehta, K.C., Smith, D.A. (2000). The Development of Wind Damage Bands for Buildings.*Journal of Wind Engineering and Industrial Aerodynamics*, 84(1), pp. 119–49

Vickery, P.J., Skerlj, P.F., Jason, L., Twisdale, L.A., Young, M.A. and Lavelle, F.M. (2006). HAZUS-MH Hurricane Model Methodology: Damage and Loss Estimation. *Natural Hazards Review*, ASCE, 7(2), pp. 84-91

Vickery, P.J., Sherjl, P.F. and Twisdale, L.A. (2000a). Simulation of hurricane risk in the United States using empirical track model.*Journal of Structural Engineering,* 126(10), 1222-12

Vulnerability Atlas of India (1997) (Earthquake, Wind Storms and Flood Hazards Maps and Damage Risk to Housing), Report,part2,Expert Group on Natural Disaster Prevention, preparedness and Mitigation having bearing on Housing and Related Infrastructures, BMPTC, Ministry of Urban Affairs and Employment, Government of India